eRHIC – the future?

Steve Peggs

- **The EIC Accelerator Workshop, Feb 2002**
- **Ultimate performance**
- **Storage ring issues**
- **Interaction region issues**

RHIC Retreat, Montauk, March 2002

The Facility Requirements

- Collider geometry capable of e- A and polarized e- p Collisions
- Range of $s^{1/2}$ for e- A as high as possible: (~ 63 GeV/u)
- Range of variable $s^{1/2}$ for e- p: 30 – 100 GeV

  Ü (Beam Energy)M_{ax}: (Ee)10 GeV, (Ep) 250 GeV, (EA) 100 GeV/u
- E_p/E_e, E_A/E_e: preferably independent of $s^{1/2}$ for detector geometry?
- Range of Ion Species: As wide as possible, p to U?
- Polarization: 70% × 70%
- Luminosity: 10^{33} $cm^{-2}s^{-1}$ per nucleon
- Integrated Luminosity for Significant Physics:

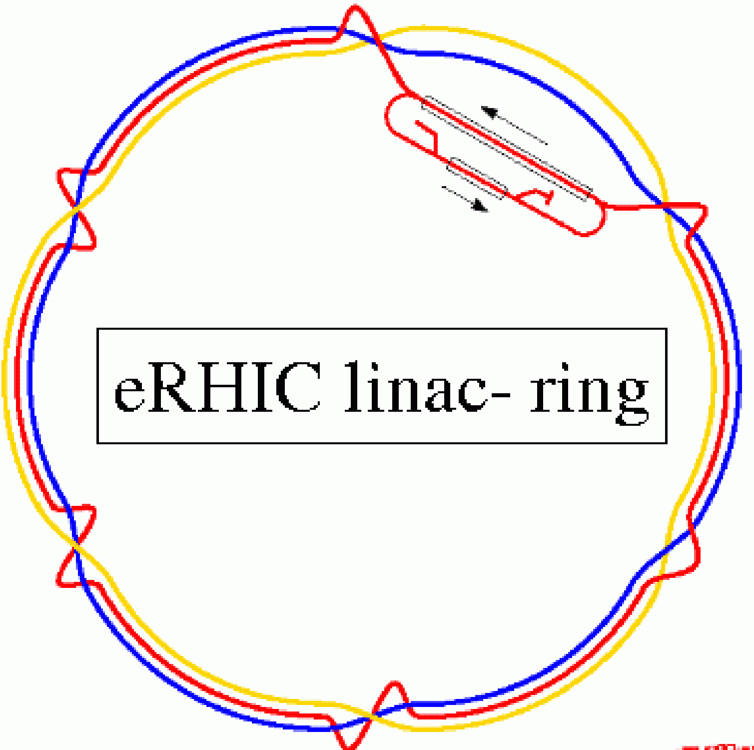
For inclusive physics (Yale workshop): ~2 fb- 1

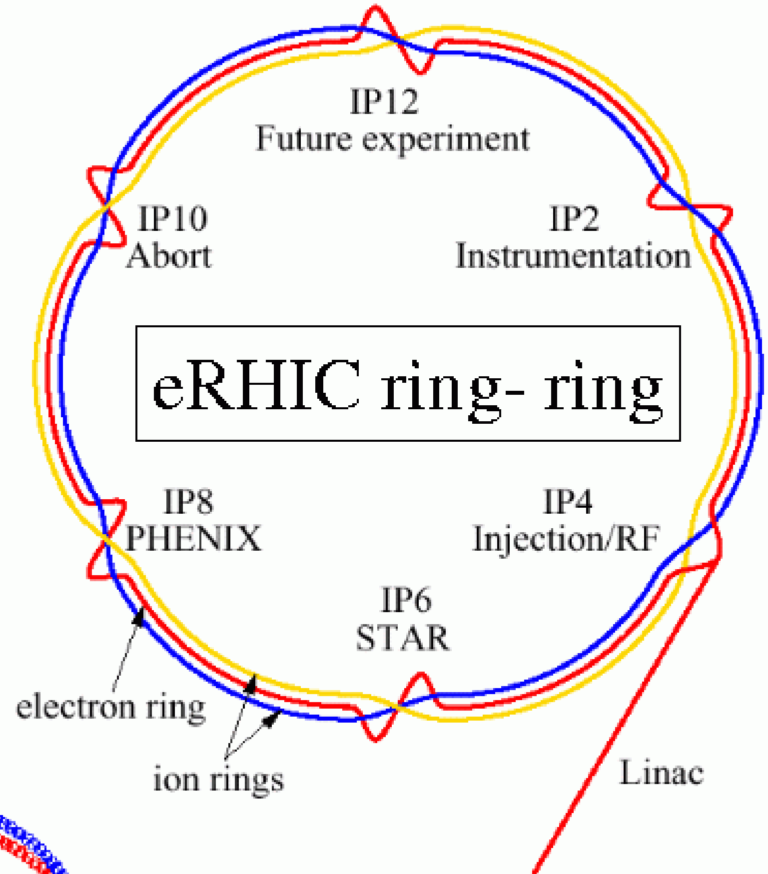
For exclusive and semi- inclusive: ~5 $\mapsto$ times more

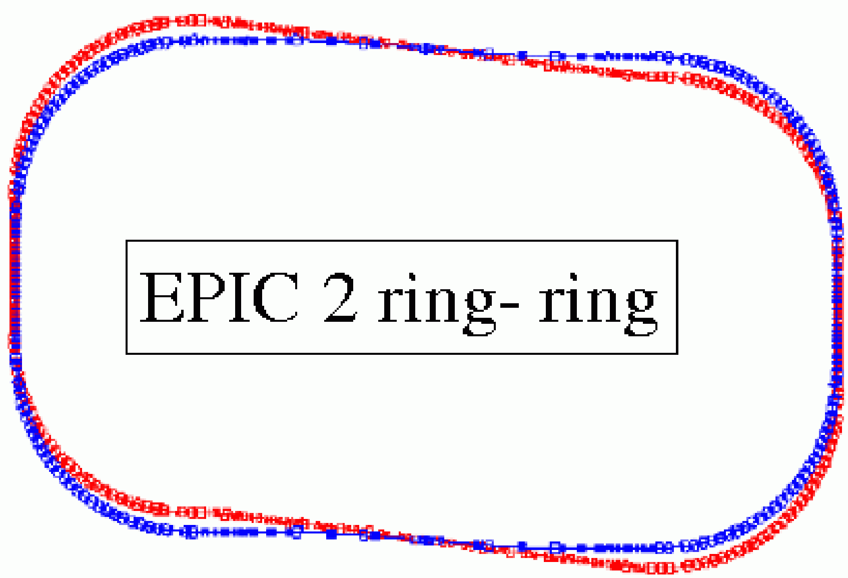
- $e^{+}p$, in addition to $e^{-}p$, requirement?

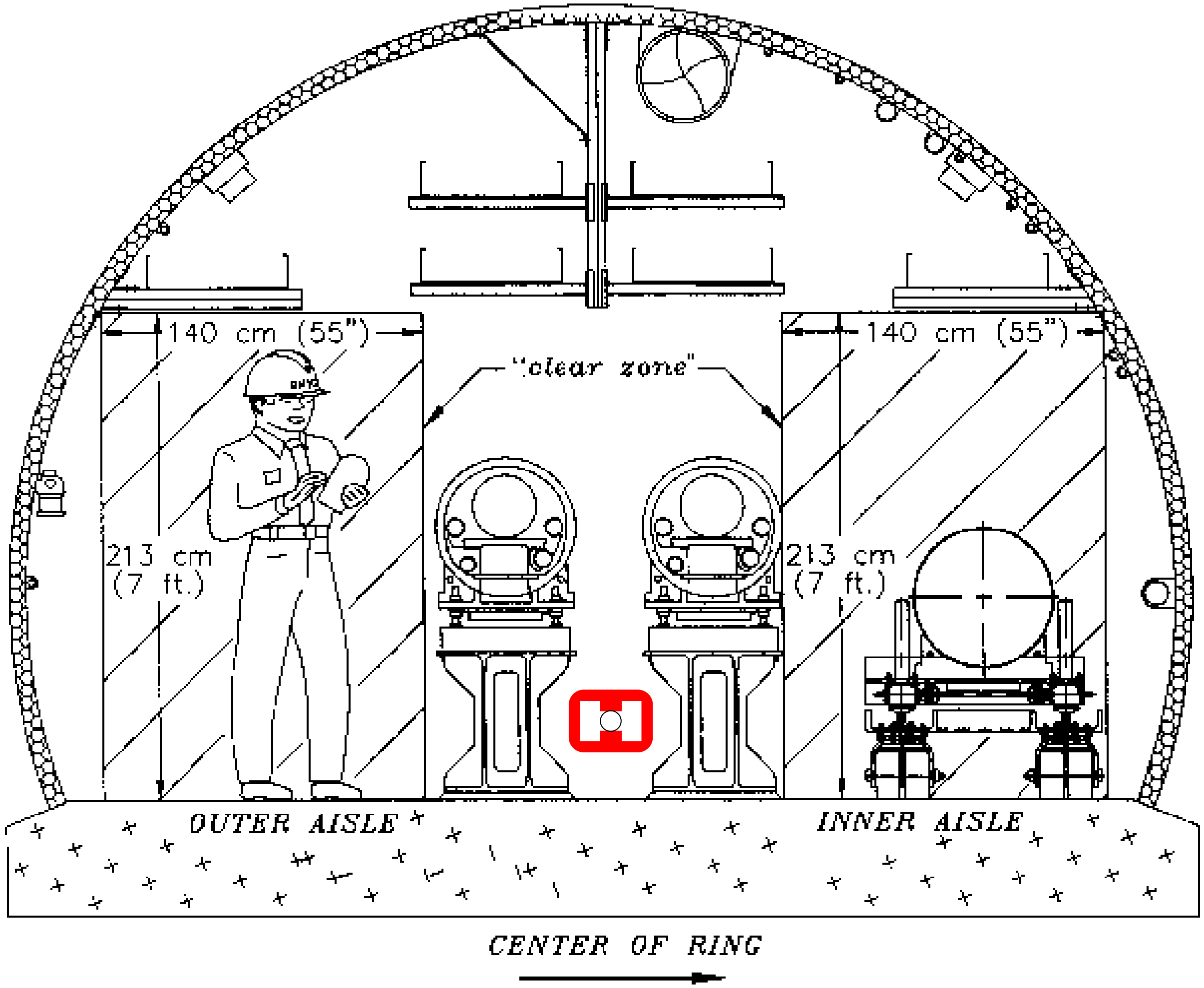
To be addressed by Electron Ion Collider Workshop

White paper EIC options



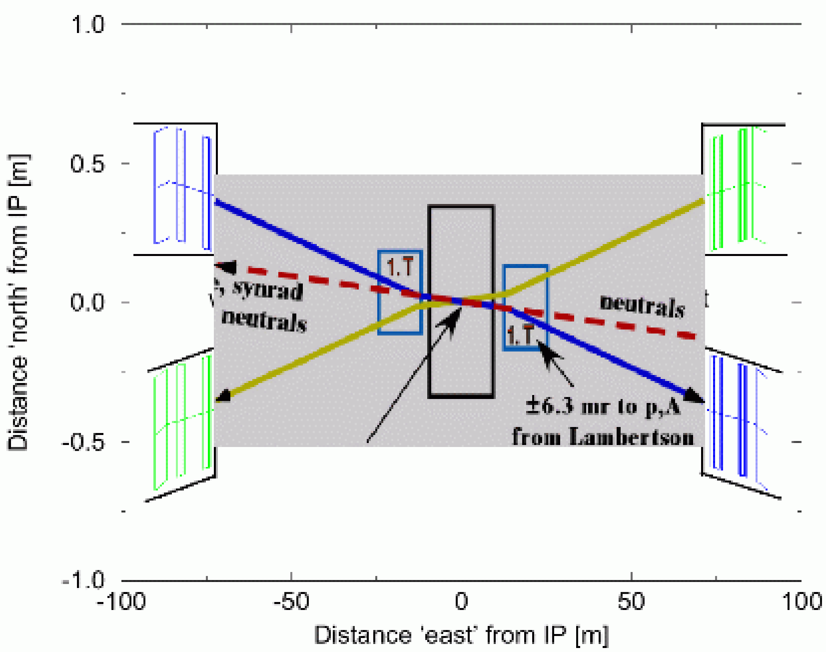


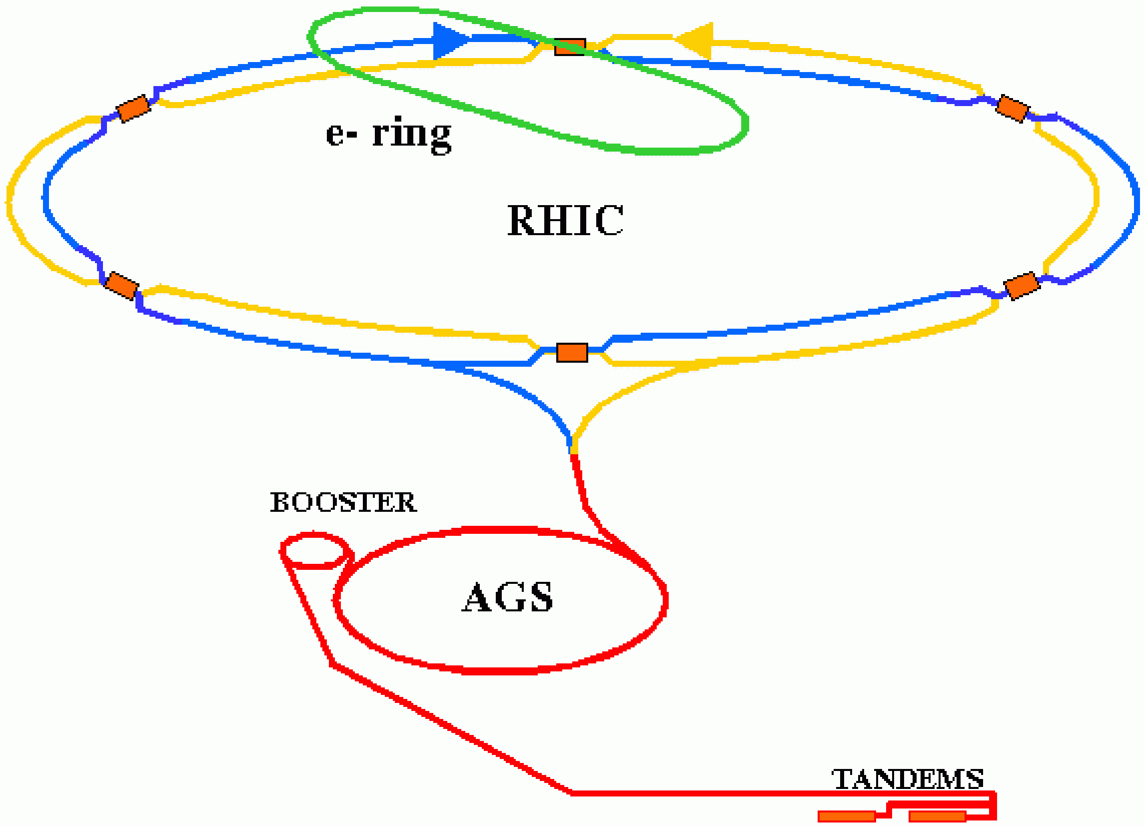




Decision: **DON'T DO THIS!**

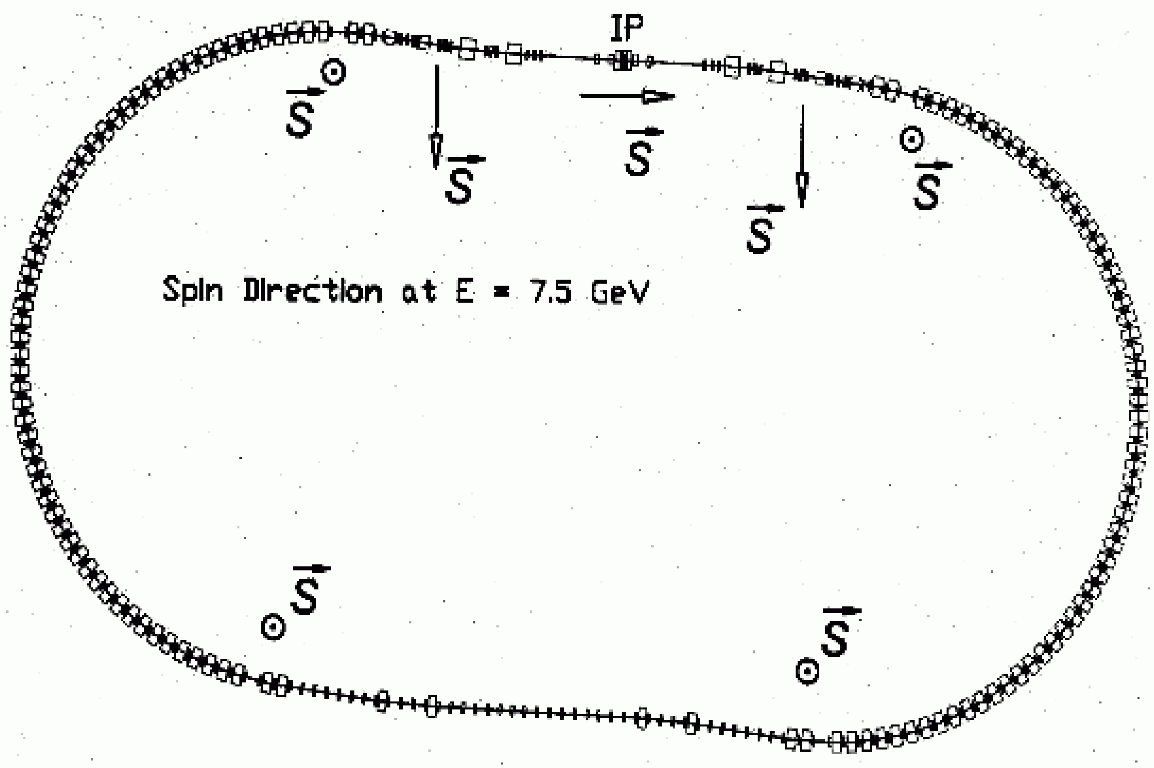
- Collisions only at one interaction region (IP12 ?)
- e- ring outside of RHIC tunnel with ¼ of RHIC circumference
- e- ring built to support polarization build- up or circulator ring for full energy (energy recovering) linac
- Existing RHIC IPs fully negotiable for electron- ion collisions

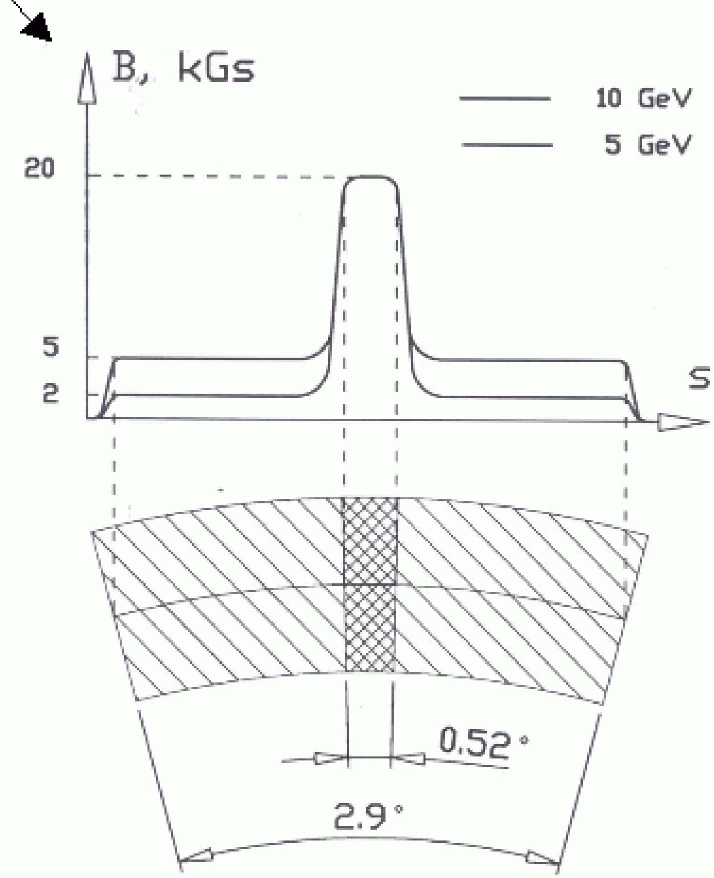




5 – 10 GeV electron ring (Y. Shatunov)

- Spin rotators: solenoid + weak horizontal bend
- Short self polarizing time using "super bends"
- ¼ of RHIC circumference





Ring- ring parameter (Y. Shatunov)

	Units	Electron ring	Proton ring
Circumferences	m	958.25	3833
Energy	GeV	5–10	25–200
Arc radius	m	97.98	610
Bending radius	m	63.59	243
Number of bunches		90	360
Bunch spacing	m	10.65	10.65
Bunch population		$1 \cdot 10^{11}$	$1 \cdot 10^{11}$
Beam currents	A	0.45	0.45
Harmonic number		1170	2520
RF frequency	MHz	365.7	196.9
Accelerating voltage	MV	30	1.5
Energy losses/turn	MeV	2.83–21.26	
Total radiated power	MW	1.27–9.57	
Beam emittances, $\varepsilon_{x,z}$	$\mu m \cdot mrad$	43–65	48–6
Beta function at IP	cm	10	10
Beam size at IP, $\sigma^*_{x,z}$	μm	65–80	68–24
Momentum spread		$1.0–1.6 \cdot 10^{-3}$	$1.1–0.4 \cdot 10^{-3}$
Bunch length, σ_l	cm	1–2	10–5
Beam-beam parameter, ξ		0.046–0.023	0.009–0.002
Lasslett tune shift, $\Delta\nu$			0.2–0.009
Luminosity	$cm^{-2}s^{-1}$		$0.45–1 \cdot 10^{33}$


DEER LEEP ROAD
FOREST PATH
WHITE PINE PATH
WEST FIFTH FIRE BREAK
COMPOST CENTER

All EIC options require e- cooling of ions

Electron cooling of high energy proton or ion beams:

- Feasibility supported by study produced at BINP
- Bunched electron beam requirements for 100 GeV/u gold beams:
  E = 54 MeV, <I> ≤ 100 mA, electron beam power: ≤ 5 MW!
- Requires high brightness, high power, energy recovering superconducting linac, almost identical to IR FEL at TJNAF
- First linac based, bunched electron beam cooling system used at a collider
- First high p_t electron cooler to avoid recombination of e^- and Au^{79+}

New ideas (Y. Derbenev):

- Use circulator ring for e- cooling of very intense ion beams
- Cooling is improved if cooling decrements are equal in all 3 dimensions
- E- cooling can produce flat beams and very short ion bunches which can improve collider luminosities

ULTIMATE PERFORMANCE

Beam-beam parameters (round beams):

$$\xi_e = \frac{N_i}{\epsilon_e}\left(\frac{r_e Z}{4\pi\gamma_e}\right) \tag{1}$$

$$\xi_i = \frac{N_e}{\epsilon_i}\left(\frac{r_i (v/c)_i}{4\pi Z}\right) \tag{2}$$

Emittance subscripts are correct! For example, e-cooling reduces ϵ_i and allows N_e to be reduced.

Electron-ion luminosity can be written

$$L = F_c\,\xi_e\xi_i\,\sigma_e'^*\sigma_i'^*\left(\frac{4\pi\gamma_e\gamma_i}{r_e r_i}\right) \tag{3}$$

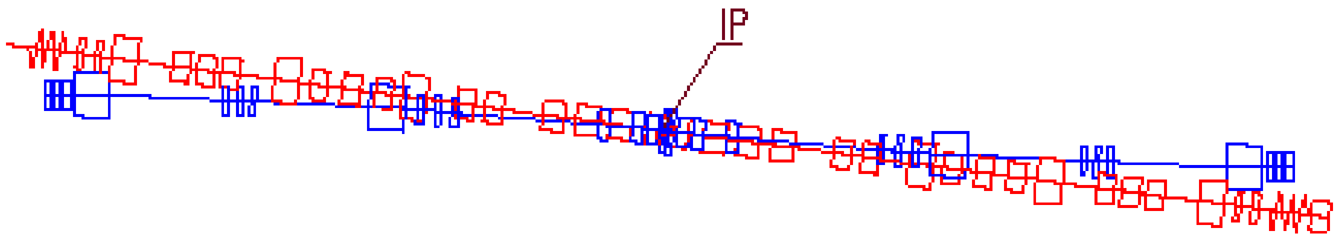
- When beam-beam limits and angular apertures have been met, $\xi_e\xi_i\sigma_e'^*\sigma_i'^*$ is fixed.

- Then the only way to increase the luminosity is to increase the collision frequency F_c (more bunches)

- Linac-ring collisions allow the usual $\xi_e \approx 0.06$ limit to be violated.

ION STORAGE RING ISSUES

Long range beam-beam. Early beam separation is easy with very unequal rigidities. EPIC:



Electron cloud. Ionized electrons are accelerated by the next ion bunches, possibly with runaway, threatening cryogenic heat load, instabilities.

• A paucity of data from superconducting rings (Tev, HERA, RHIC, LHC). More work required ...

Intra-Beam Scattering, electron cooling. RHIC expects the gold rms emittance to grow from 2 μm to 7 μm in 10 hours. With electron cooling it should shrink to about 1 μm in 1 hour.

ELECTRON STORAGE RING ISSUES

Synchrotron radiation. The total synchrotron power is

$$P\,[\mathrm{MW}] \;=\; 0.0885\,\frac{E^4\,[\mathrm{GeV}^4]}{\rho\,[\mathrm{m}]}\,I\,[\mathrm{A}] \tag{4}$$

• The SLAC HER serves as a natural "ruler" to compare prospective electron rings. (See Table).

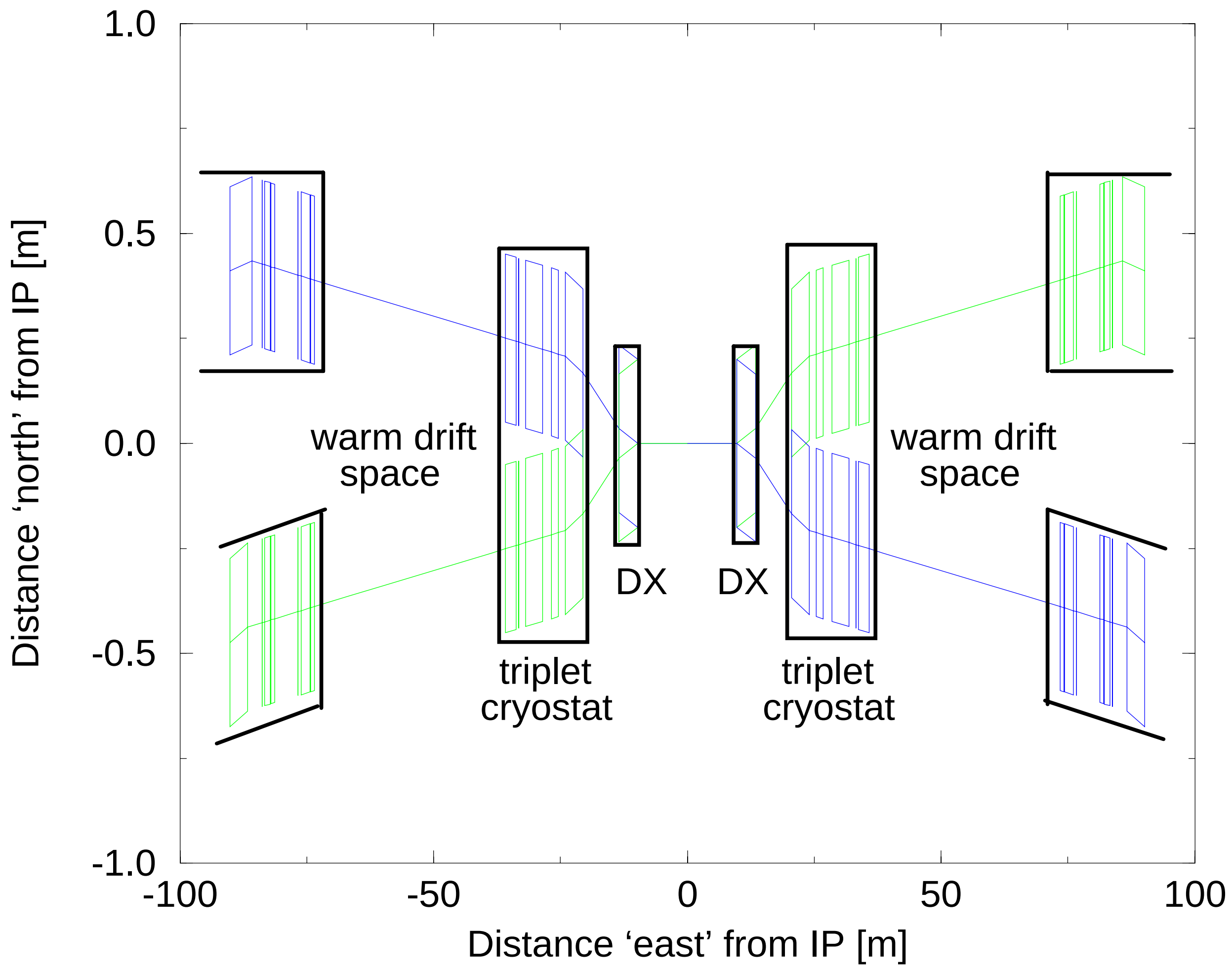
• Must limit synchrotron radiation load to less than 15 kW/m.

Polarization. The natural polarization time

$$T_{\mathrm{pol}}\,[\mathrm{s}] \;=\; 15.8\,\frac{C\rho^2\,[\mathrm{m}^3]}{E_e^5\,[\mathrm{GeV}^5]} \tag{5}$$

• Acceleration through intrinsic spin resonances probably impossible ($E = J\,0.441$ [GeV]).

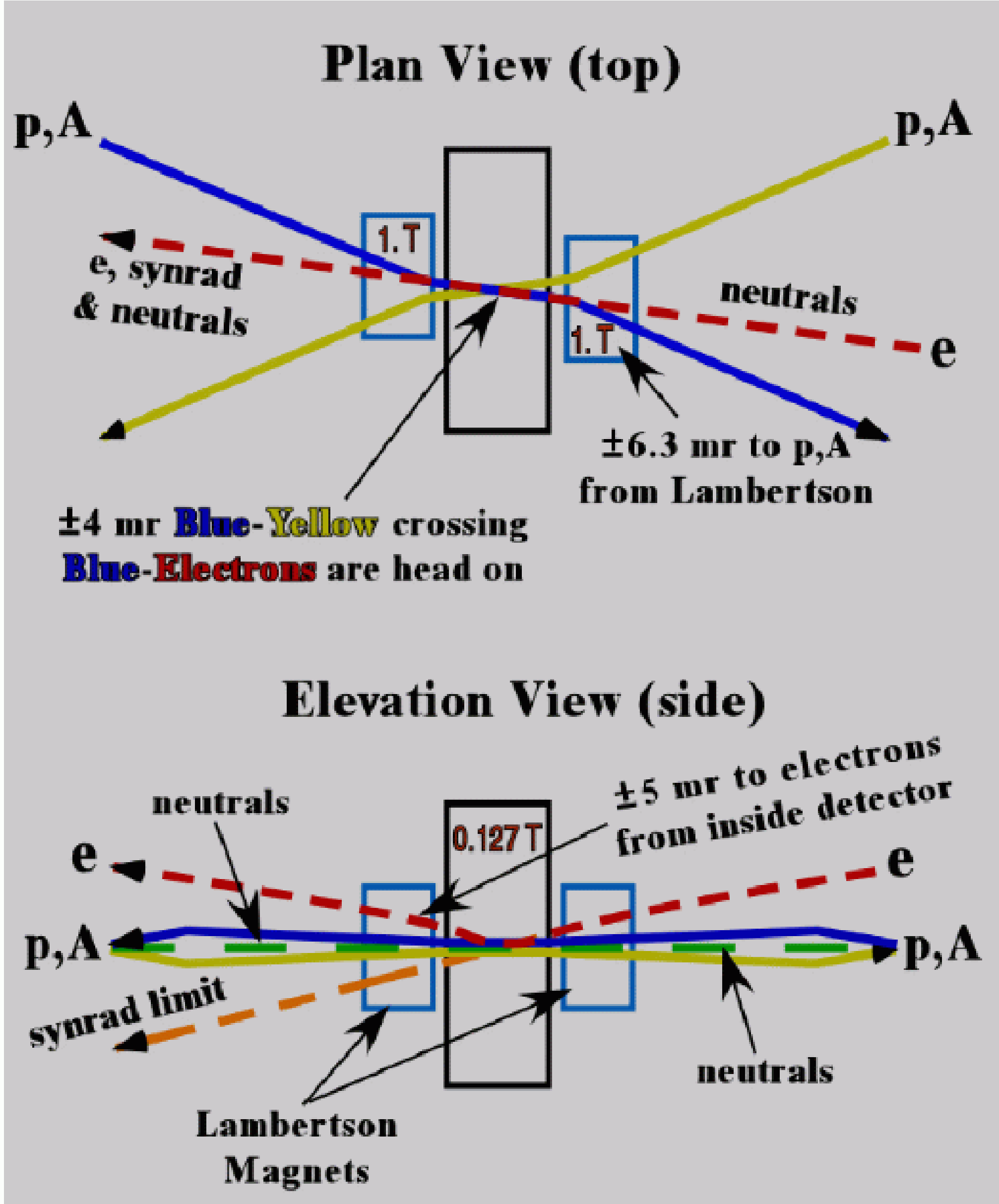
INTERACTION REGION ISSUES



The IR geometry is FULLY negotiable

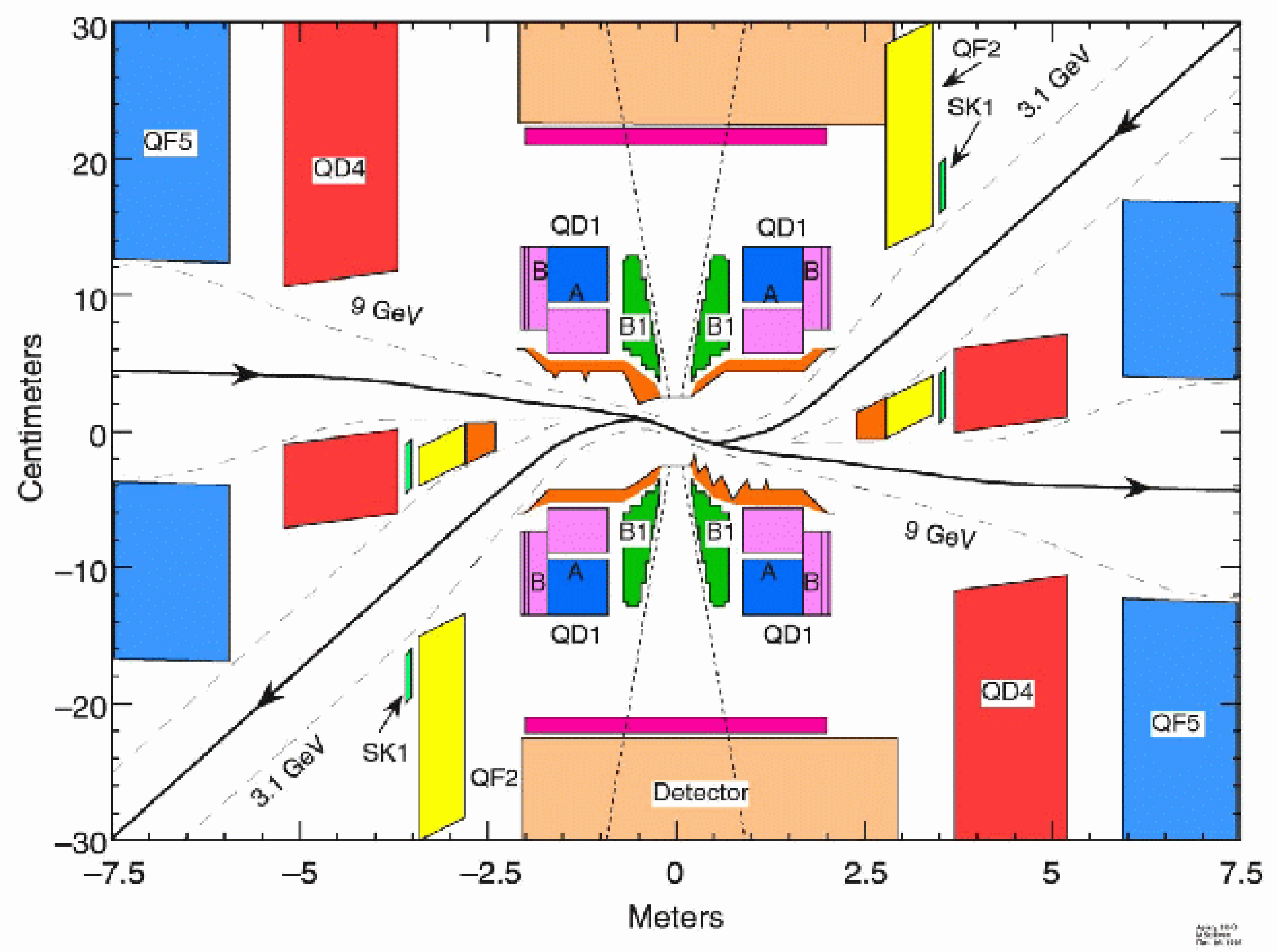
eRHIC IR with “weak – strong” bends (B. Parker)

- “Three beam” IR
- E- beam collides head on with blue at IP
- Small vertical deflection inside detecto separates electrons from circulating beams
- Ions bent by 1T field inside a Lambertson dipole
- Long drift downstream of Lambertson gives spectrometer lever arm
- Keep Lambertson short to pass synchrotron radiation.
- Small vertical kicks to Blue/Yellow beams compensate before triplets – proton spin should be OK



PEP-II IR Schematic

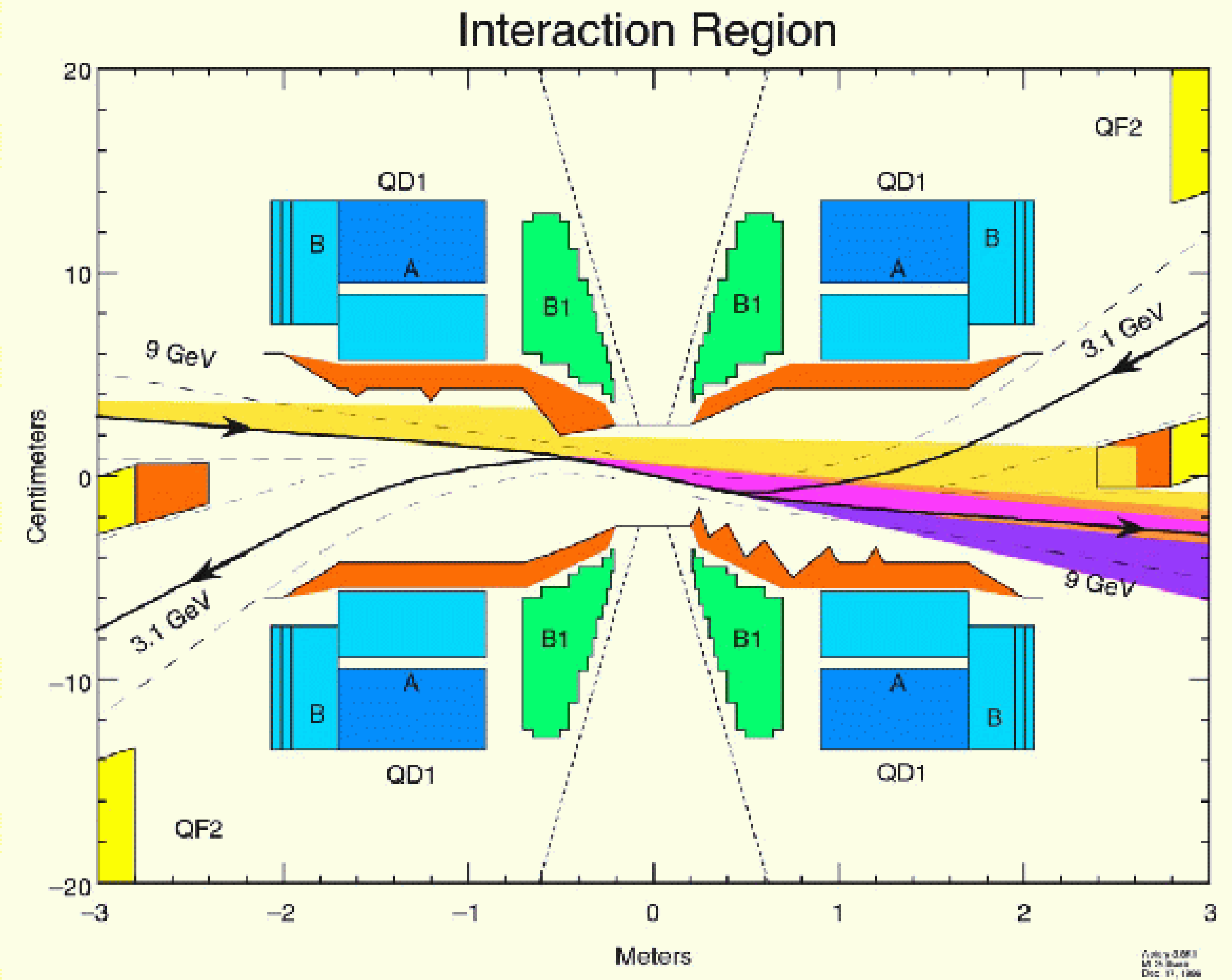
M. Sullivan



U. Wienands, SLAC-PEP-II
EICAW IR talk ppt, 26-Feb-02

PEP-II IR with HEB SR Fans

M. Sullivan



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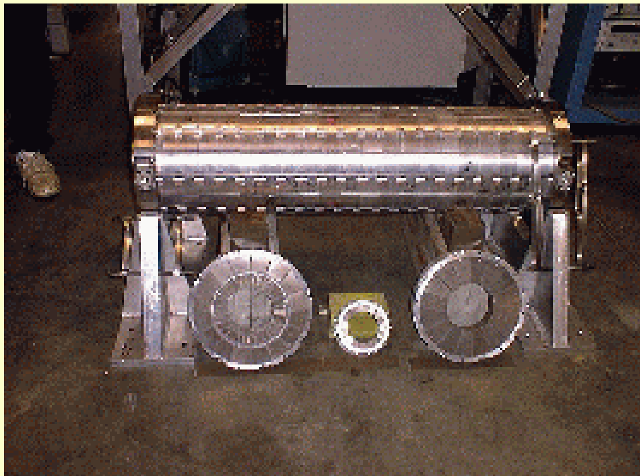
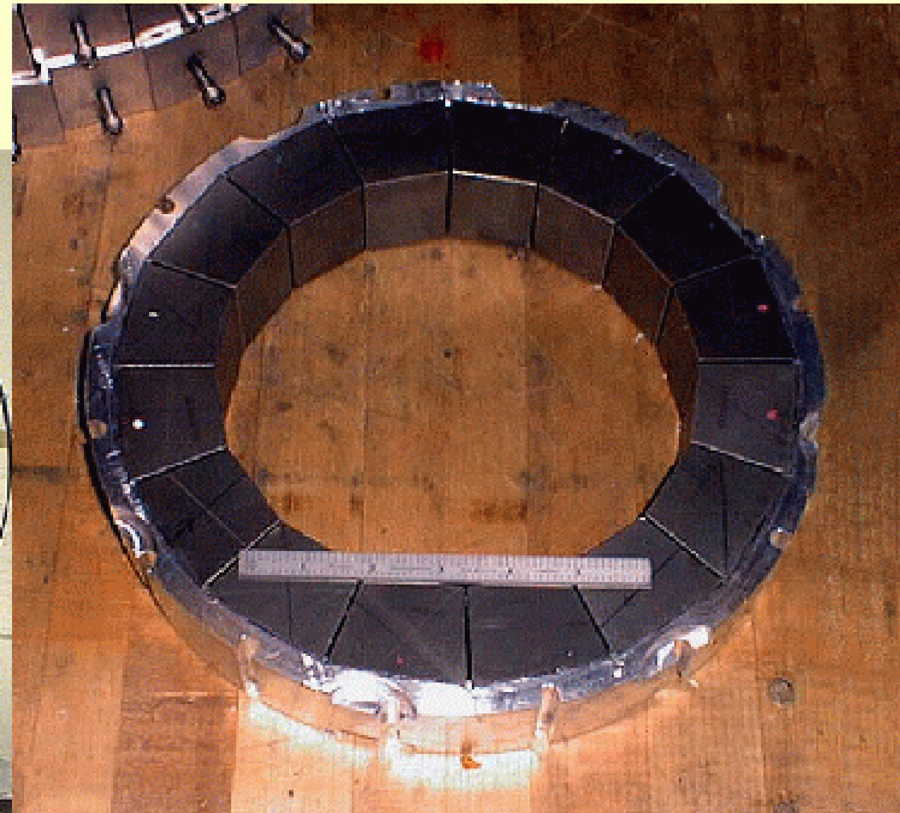
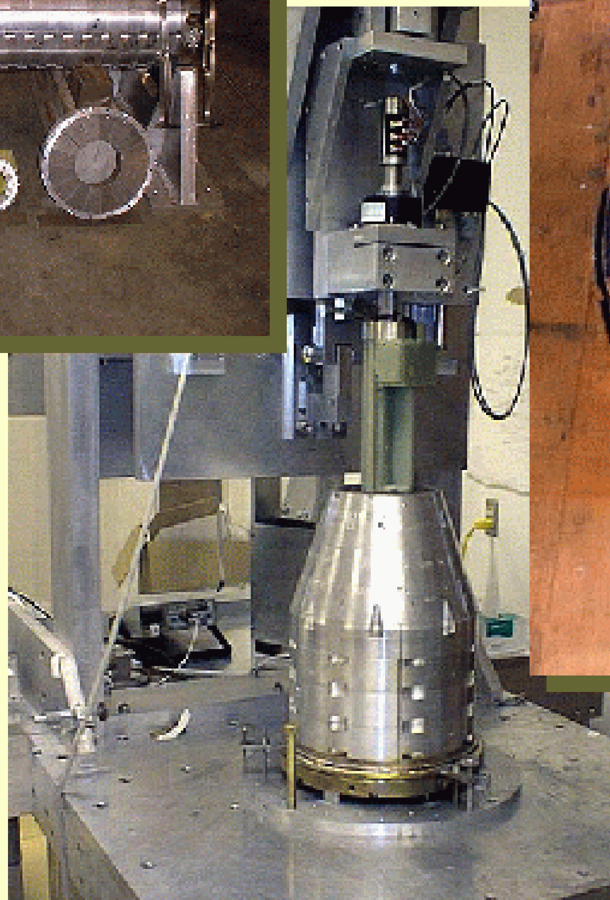
IR SM_2Co_{17} Magnets

Q1 magnet & rings



Q1a ring





B1 magnet in measurement

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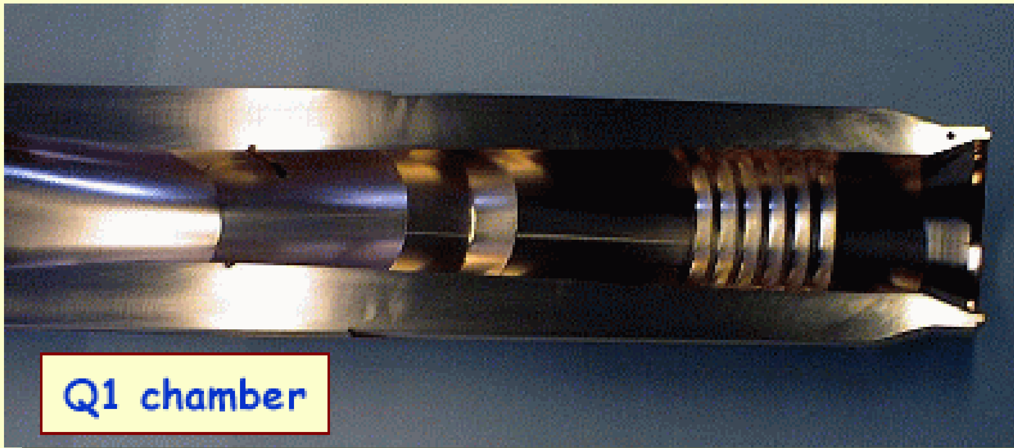
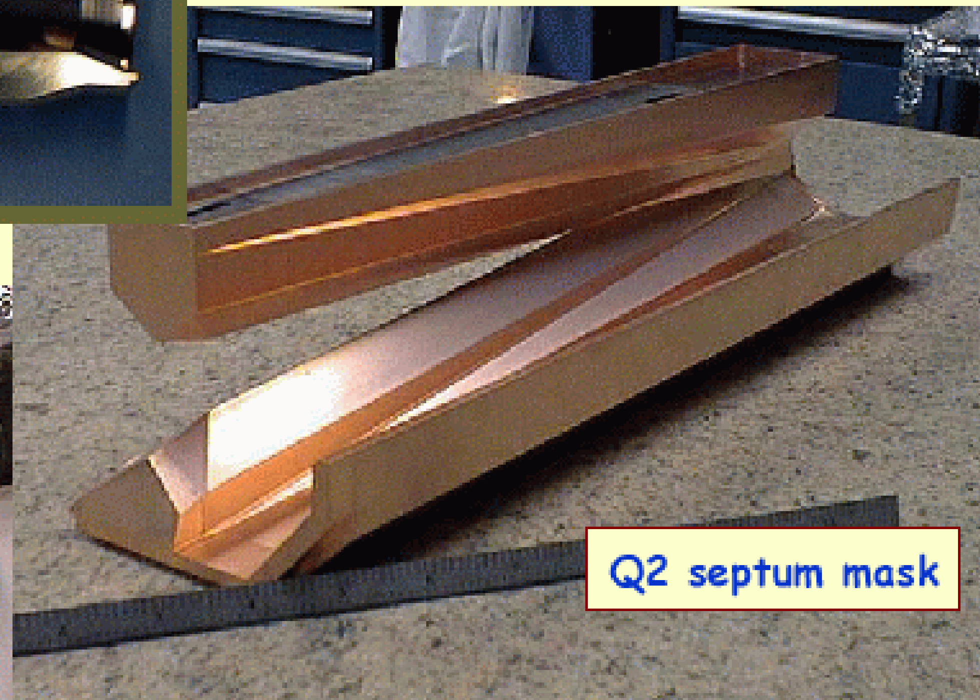
IR Vacuum Chambers


Q1 chamber


Q2 septum mask


Be vertex chamber

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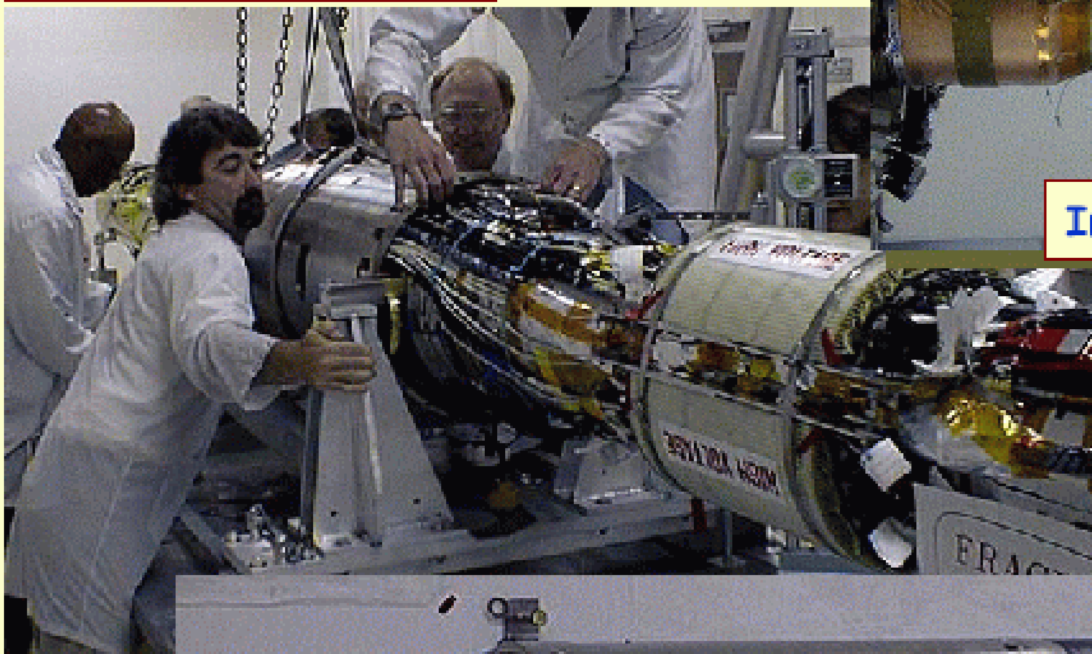
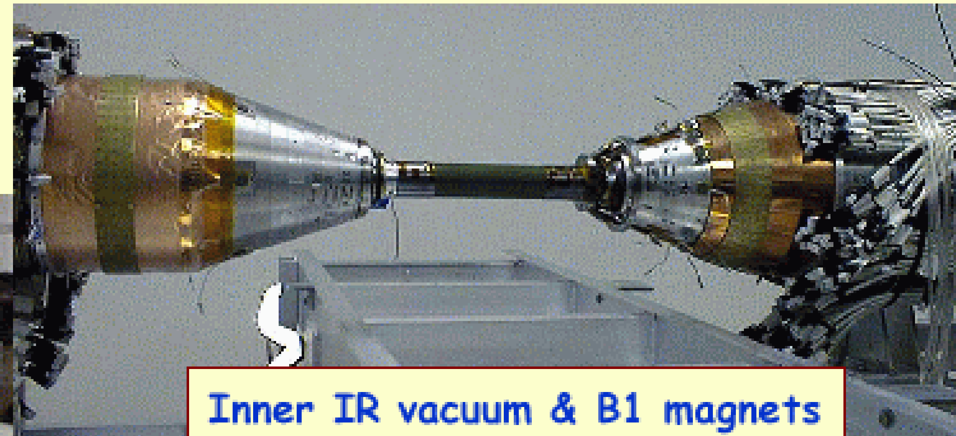
IR support Tube Assy

Support tube assembly



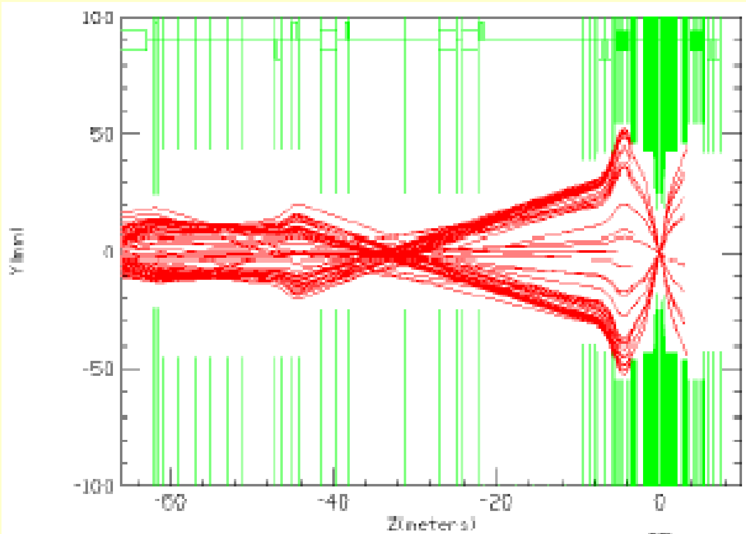


Inner IR vacuum & B1 magnets

Support tube assembled

Lost-Particle Backgrounds

W. Kozanecki

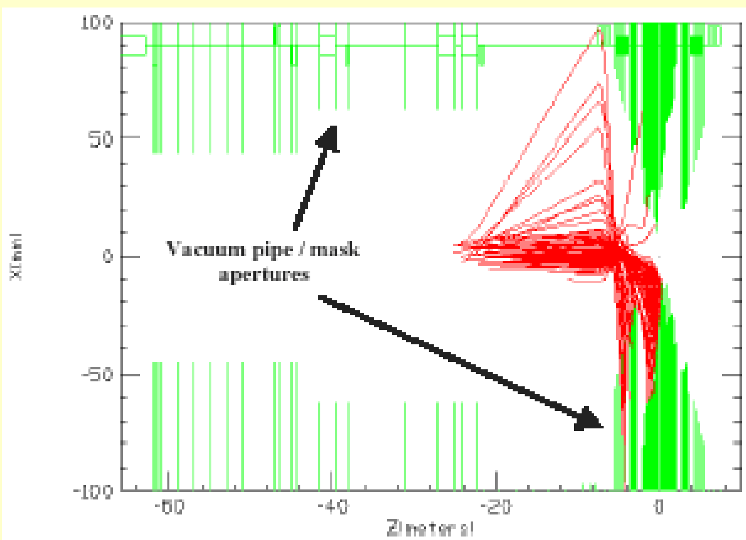


IP

Coulomb scattering

in Arcs

(distant)

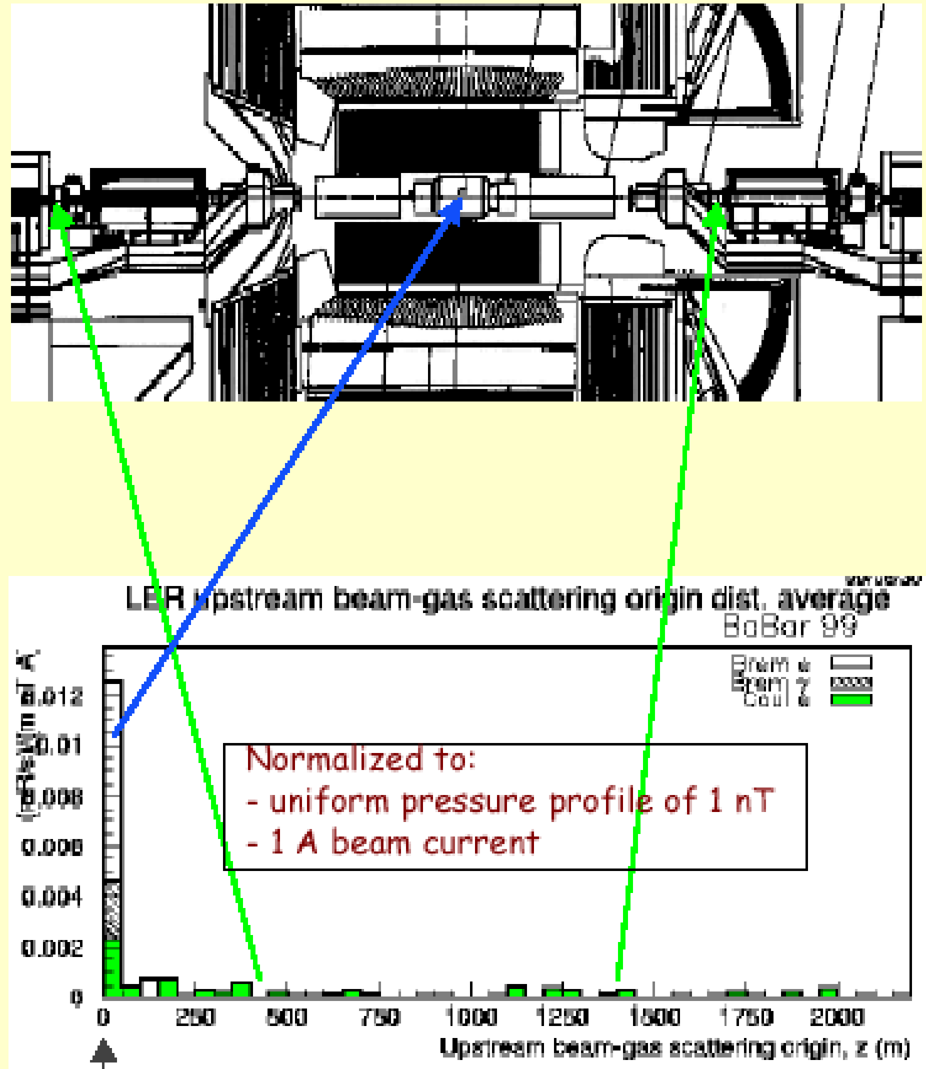


e⁻ Brems-strahlung

in last 26 m

(near IR,

x-plane)



IP

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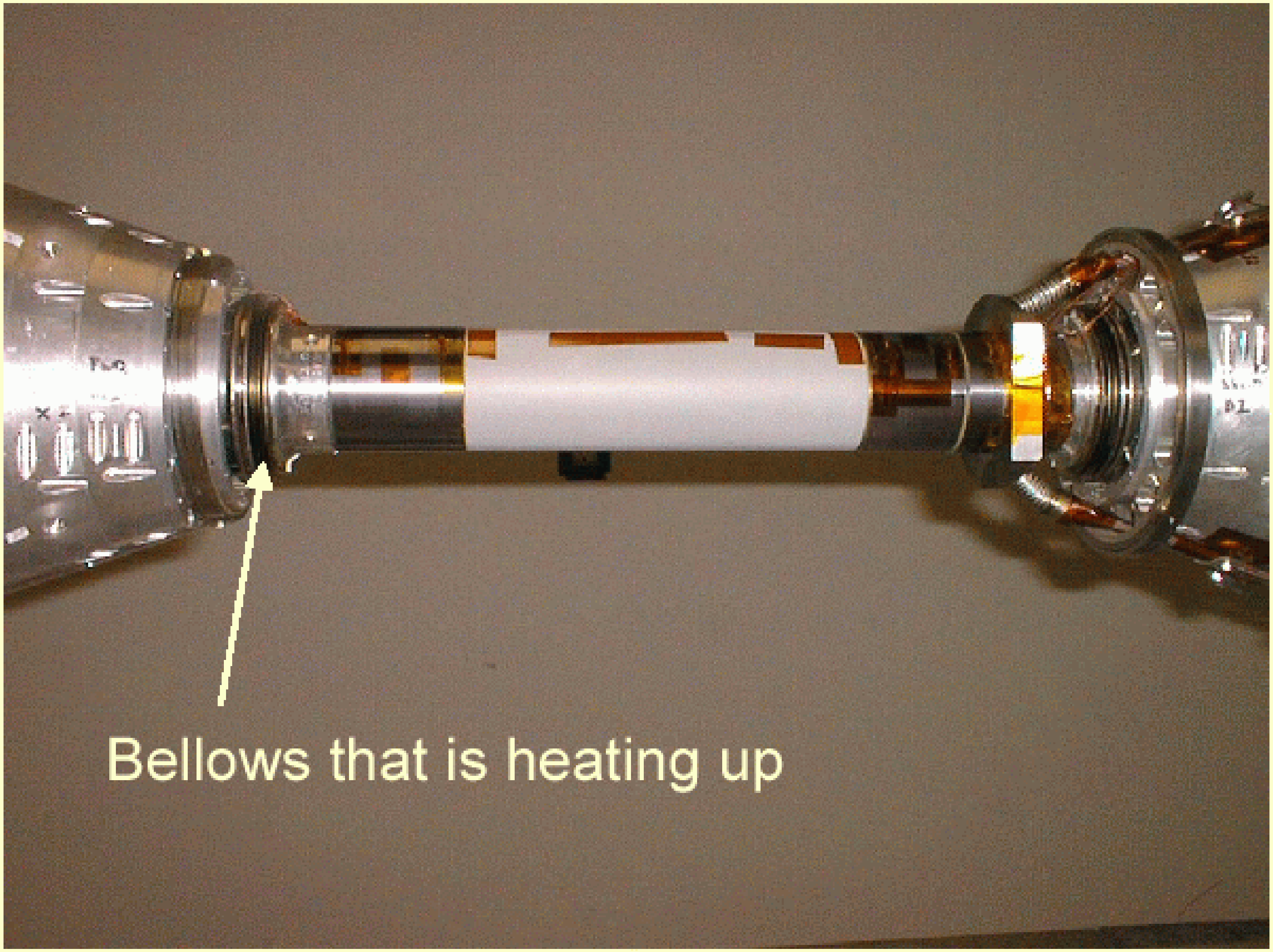
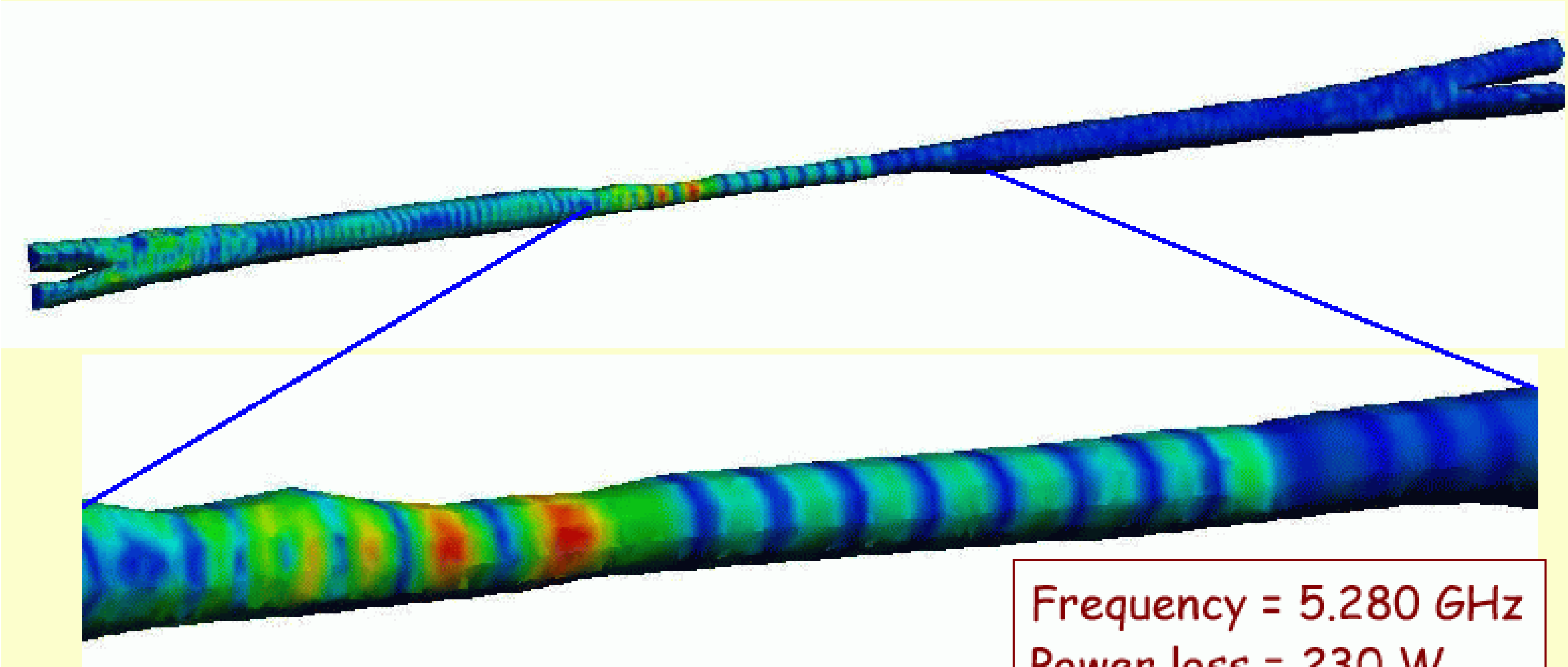
Be beam pipe at the center of BABAR



Mode at Forward Mask

N. Folwell, C. Ng



Frequency = 5.280 GHz
Power loss = 230 W

SUMMARY

1. There is a growing consensus that BNL is the right place to build EIC, also known as eRHIC.
2. The largest feature would be an electron storage ring, perhaps 1/4 of the RHIC circumference (~ 1 km).
3. This ring could first operate as a storage ring, and later be upgraded to a “1,000” turn recirculator
4. What is the electron injector? Multi-pass SCL? Upgradable?
5. The IR has a host of challenging problems, familiar to B-factories (SLAC, KEK, Cornell) and to HERA.
6. **How do we collaborate from here?**